Times of October 17, it is stated that this blasting was sub-let to a firm of contractors and was done by men on piece-work.

There appear to be at least three commissions investigating the accident: one, appointed by the Reichstag, another by the Bavarian Government, and a third by the Workmen's Council of the Oppau factory, and it is gathered that there is some conflict as to the powers and status of these commissions. An adjournment of the inquiry has evidently been made, but it is not clear as to whether this is for the purpose of obtaining further evidence on the danger of blasting, or, as is suggested by the writer of an article in the *Chemiker-Zeitung* of October 6, on danger that may arise from heating up of the mass through the liberation of nitric acid from ammonium nitrate by the acid held as an impurity in the ammonium sulphate. With regard to the latter point, it is stated that the representatives of the factory are taking a continuous record of the temperature of the remaining stock, which amounts to 8,000 tons, with the object of flooding it if any considerable rise occurs.

In view of the importance of ammonium nitrate and other salts of ammonia for fertiliser purposes on the very largest scale, it is to be sincerely hoped that every endeavour will be made by the Inter-Allied Commission of Control to obtain the final report of the German Parliamentary Committee, together with a record of any experiments conducted to elucidate the cause of the explosion.

The Age of the Earth.[1]

By the RIGHT HON. LORD RAYLEIGH, F.R.S.

THE subject which we have met to consider to-day is encumbered with past controversy. It cannot be denied, I am afraid, that exponents of particular views in the past have laid too much emphasis on their own particular way of looking at the problem without making enough allowance for human fallibility. I shall try, so far as possible, to avoid this pitfall. There has been a tendency on all sides for specialists in one branch of science to consider themselves free to disregard evidence drawn from a class of considerations with which they are not familiar. I am sure that this is not the road to truth. In attempting a problem of this kind, when we seek to plumb into the depths of time, far beyond human experience, we cannot afford to neglect evidence drawn from any quarter, even if it is not the kind of evidence which we find it most congenial to contemplate. A parallel case is that of a jury of plain men in a murder trial. They may know nothing of medical jurisprudence, post-mortem examinations, and so on. They may even consider the subject repellent; but that does not exempt them from the duty of fully considering and weighing such evidence to the best of their ability. The witnesses in the trial have, however, to limit themselves to matters with which they are personally conversant. I will try to give my evidence within these limits.

The phrase "age of the earth," though rather vague, is perhaps definite enough for our purpose. What we want to know is, how long has the earth's surface been fitted for the habitation of living beings? or, alternatively, how long has it taken to accumulate the known series of geological formations? These questions are not the same, but I do not think that we shall need to insist on the distinction this morning.

Lord Kelvin's arguments depended on attempts to limit the length of time during which the earth's surface temperature could have remained substantially the same as at present, and he attacked this problem from two different points of view. In the first place, he attempted to set a limit of time to the duration of the sun's heat; and secondly, from consideration of the earth's internal heat, he argued back to the time when the surface was too hot for the presence of living beings. I have heard a suggestion that there is some mutual inconsistency in these two lines of argument—consideration of the sun's heat makes the past temperature too low; consideration of the earth's heat makes it too high—but I do not think that this criticism is more than superficially plausible. The point was rather that from either of these arguments a condition widely different from the present would be reached, and therefore that, even if there were some unrecognised flaw in one of the arguments, the other would stand. Possibly, looking back into the remote past, a condition of the earth's surface is imaginable where the mean temperature was much the same as at present, heat coming from the earth's interior in compensation for a diminished radiation from the sun; but I feel sure you will all agree with me that we cannot get more time by special pleading of this kind. The fossiliferous rocks have, without doubt, been accumulated under conditions of solar radiation not essentially different from the present. One simple consideration is that the plants in the coal measures obviously had green leaves, and that these could not function without a full allowance of solar radiation.

We have then to consider whether Lord Kelvin's arguments can stand in the light of present knowledge. I think we must admit that they cannot.

First, as regards the earth's heat, it is now generally known that the premises of Lord Kelvin's calculation, carefully particularised by him, are upset by the discovery of radio-active substances in the earth. In 1906 I made a determination of the amount of radium in the superficial parts of the earth which are alone accessible. From radium analysis we can calculate the amount of uranium and other associated substances and the thermal output from them, and the result is to show that if we suppose the same radium content to extend to a depth of some 20 miles, the whole output of heat would be accounted for without assuming that any of it comes from the store of primeval heat as postulated by Lord Kelvin. It is without doubt difficult to understand why the output of heat is not greater, for it would certainly be expected that the rocky crust of the earth would be more than 20 miles thick, to say nothing of any radium there might be in the unknown interior.

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[1] Contributions to a joint discussion of the Sections of Mathematical and Physical Science, Geology, Zoology, and Botany of the British Association at Edinburgh on September 13.

Can we at present infer anything definite from the earth's internal heat as to the possible duration of geological time? I think practically not. It appears certain that the radio-active materials present in the earth are generating at least as much heat as is now leaking out from the earth into space. If they are generating more than this (and there is evidence to suggest that they are), the temperature must, according to all received views, be rising. In a word, we are puzzled to explain the existing state of things, and cannot use it as a firm basis from which to explore the past.

Next, as to the sun's heat. Lord Kelvin's argument was that we knew of no possible source at all adequate to supply the existing output of solar energy except secular contraction, and even this source of supply was not enough to account for more than twenty million years of solar heat in the past. It is impossible to condemn on principle arguments of this kind. We often must, and do, rely on them in science as in everyday affairs; but a certain reserve is always needed on the ground that there are more things in heaven and earth than are dreamt of in our philosophy. Knowledge which has accumulated since Lord Kelvin's time has driven us back on this alternative.

The sun is only one of the host of stars, and if we find it impossible to account adequately for their radiation by contraction it evidently will not do to assume that the sun is limited to this source of supply.

Now some of the stars (the giant red stars), though of about the same mass as the sun, are radiating energy at something like one thousand times the rate that the sun does. They ought, according to the contraction theory, to have expended a considerable fraction of their total energy in historical times. No one will maintain that this has occurred, and if not there must be some source of supply other than contraction. It is not necessary for our immediate purpose to inquire what this source is. It is enough to note that its existence invalidates Lord Kelvin's estimate of the age of the sun's heat.

Modern knowledge in radio-activity has given what appears, if separately considered, to be a firm and satisfactory basis for the estimation of geological time. Uranium, for example, goes through a series of changes (radium is one of the stages in its progress), changing eventually into an isotope of lead—that is, an element chemically indistinguishable from lead, except by a slight difference of atomic weight and (practically at least) inseparable from ordinary lead by chemical means if once mixed with it. The isotope of lead in question has probably an atomic weight of 206 exactly, as contrasted with an atomic weight of 207·1 for ordinary lead.[2] This is much less than the atomic weight of uranium (238·5), and the difference represents approximately the weight of helium atoms, which are the debris shed at the various stages of the transformation.

Further, it is well established that a gram of uranium as found along with its products in rocks and minerals is now changing at a rate represented by the production of $1{\cdot}88 \times 10^{-11}$ grams of helium and $1{\cdot}22 \times 10^{-10}$ grams of lead isotope per annum. We have not time this morning to consider the methods by which these figures have been reached. It must suffice to say that in the case of helium it amounts practically to direct observation, while in the case of lead isotope the evidence, though less direct, is very strong, and, so far as I am aware, is not contested by any student of the subject. I have said that this is the rate at which one gram of uranium as found in the earth is producing helium and lead isotope at present. It is important to inquire whether one gram of uranium did the same in the past. This we cannot, of course, determine directly. It is certain that nothing we can do in a laboratory in the way of change of temperature and pressure can alter the rate sensibly, and enough has been done in this way to make it unlikely that any pressures and temperatures encountered in the superficial parts of the earth could have such an effect. It has been suggested by Prof. Joly that the absolute age of a gram of uranium may affect its rate of disintegration. All possibilities should be considered, but this suggestion derives no support from the behaviour of the shorter-lived radio-active substances the behaviour of which we can watch.

Upon the whole, therefore, it would seem that in the disintegration of a gram of uranium we have a process the rate of which can be relied upon to have been the same in the past as we now observe it to be.

The application is either to individual uranium minerals or to the earth's crust as a whole. Taking first the minerals containing uranium, these are found in all cases to contain helium and lead. The helium in them, which appears to be retained mechanically, may safely be treated as wholly a radio-active product. The lead in some cases conforms closely to the expected atomic weight of 206, about one unit lower than common lead, and in such cases we may safely regard the whole of it as a product of uranium disintegration.

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[2] Ordinary lead may partly consist of it, but this is not yet certain, and not very important for the immediate purpose.

Thus take the broggerite found in the pre-Cambrian rocks at Moss, Norway. The lead in this mineral has an atomic weight of 206·06 as determined by Hönigschmied and Fräulein St. Horovitz. The ratio of lead to uranium is 1 : 3. Taking the lead as all produced by uranium at the rate above given, we get an age of 925 million years. Some minerals from other archæan rocks in Norway give a rather longer age.

In other cases there is some complication, owing to the fact that thorium is associated with uranium in the mineral and that it, too, produces helium and an isotope of lead of atomic weight probably 208 exactly, about one unit higher than common lead.

In a third class of cases the uranium mineral, pitchblende, occurs in a metalliferous vein, and the lead isotope produced in the mineral is diluted with common lead which entered into its original composition.

These various complications introduce a certain amount of difficulty and even ambiguity into the interpretation. A full discussion cannot be given on an occasion like the present, but the complications cannot, I think, be considered to modify the broad result.

A determination of the amount of helium in minerals gives an alternative method of estimating geological age; but helium, unlike lead, is liable to leak away, hence the estimate gives a minimum only. I have found in this way ages which, speaking generally, are about one-third of the values which estimations of lead have given, and are, therefore, generally confirmatory, having regard to leakage of helium.

The helium method is applicable in some cases to materials found in the younger formations, and proves that the ages even of these are to be reckoned in millions of years. Thus the helium in an Eocene iron ore indicated thirty million years at least.

Returning now to the estimation of lead, H. N. Russell has recently applied this line of reasoning to the earth's crust as a whole. He takes the uranium in the earth as 7×10^{-6} of the whole, and the lead as 22×10^{-6} of the whole. It is necessary to remark that we do not know very definitely whether the lead distributed in the rocks in small proportion and very difficult of extraction is the same mixture of isotope as the lead of mineral veins. We call the latter "common lead," but nearly all the lead in the earth's crust is of the former kind.

Even if we did know that "rock lead" were the same as "vein lead," we should still not be in a position to say what fraction of it was uranium-lead, as we do not know whether an isotope having an atomic weight 207 exists. If it does, obviously the problem how much uranium-lead (atomic weight 206) and how much thorium-lead (atomic weight 208) exists in common lead (atomic weight 207) becomes indeterminate in the absence of further data. An analysis of lead by positive rays will probably soon become feasible, and with a determination of the atomic weight of "rock lead" will do much to clear up the matter.

If all the lead were uranium-lead, and had been generated since formation of the earth's crust, the time required would be 11×10^9 years. This is certainly too great. Allowing for the production of some of the lead from thorium, Russell finds a period of 8×10^9 years as the upper limit. This is about six times the age indicated by the oldest individual radio-active minerals that have been examined.

I have now traversed that part of our subject of which I feel competent to speak. The upshot is that radio-active methods of research indicate a moderate multiple of 1000 million years as the duration of the earth's crust as suitable for the habitation of living beings, and that no other considerations from the side of pure physics or astronomy afford any definite presumption against this estimate.

The arguments from geology and biology I must leave to our colleagues from other sections. May I venture to say that I for one consider the topics with which they will deal as not less interesting and important than those which it has been my privilege to try to lay before you.

By PROF. W. J. SOLLAS, F.R.S.

HUXLEY once sagely remarked that the zoologist must take his time from the geological clock. The geologist is thus charged with a great responsibility which he would willingly share with the physicist and astronomer. One of the earliest attempts to determine the age of the earth by purely geological means was made by the late Dr. Samuel Haughton, who based his calculations on the rate of deposition of sediment supposed to be evenly distributed over the whole floor of the ocean. This led to the conclusion that the time which must have elapsed since the first appearance of the dry land is of the same order of magnitude as that now presented for our consideration by Lord Rayleigh.

Soon, however, it was discovered, as a result of exploration by the *Challenger*, that deposition is limited to a comparatively narrow belt bordering the continents—a limitation due to several causes, chief among them the fact that sediment sinks much more rapidly in salt water than fresh. On taking account of this factor Haughton's period was reduced to about 100 million years. At the same time a new method was devised by Prof. Joly which depends on the rate at which sodium is supplied to the sea, and this led to a similar result.

Antecedent to these attempts, another method, based on the rate at which the earth is losing heat, had been employed by Lord Kelvin, and this gave at first an estimate concordant with the preceding—*i.e.* 100 million years. Later, how-